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High Voltage Fluorescent Tubes*

By H. G. JENKINS, M.Sc., F.Inst.P., and J. N. BOWTELL, B.Sc., A.Inst.P.†

Synopsis

It is the purpose of the present paper to draw attention to some of the special characteristics of high-voltage fluorescent tubes, with particular reference to the cold cathode type available in this country at the present time. Before dealing with the tubes themselves, the various types of cathodes used in high-voltage fluorescent tubes are discussed. This is followed by a brief account of the more important luminescent materials in common use for these tubes. The limitations of mercury-filled fluorescent tubes for producing very warm light and the advantages of neon fluorescent tubes for this purpose are discussed. Reference is made to the special features of high-voltage, hot-cathode fluorescent tubes

Introduction

It is probably true to say that low pressure fluorescent lamps represent the most significant development in lighting since the invention of the tungsten filament lamp. Despite the fact that high voltage fluorescent lamps with cold cathodes have been in use in this country for general lighting purposes since 1933—several years before the development of the first mains operated types—lighting engineers are probably less familiar with their characteristics and their possibilities than they are with the newer mains voltage lamps. The introduction of the latter lamps has resulted in an increased interest in high voltage fluorescent tubes, which lends support to the view that there is an ever-widening field of application for both types. If operation is restricted to ordinary supply voltages, certain conditions concerning the dimensions and wattage, and the nature of the cathodes and the gas filling must be fulfilled. The use of voltages higher than the usual supply voltages gives the lamp designer greater scope with regard to dimensions and gas filling, and the lighting engineer more opportunity for expressing his own and his customer's ideas.

The first fluorescent tubes of practical importance were the long, narrow high voltage types with cold cathodes used extensively for advertising and decorative lighting. Modern cold cathode fluorescent tubes, with which the present paper is primarily concerned, use greatly improved phosphors and methods of processing but are essentially similar to these early tubes. It is interesting to note that hot cathodes, which were originally used to make possible direct operation from ordinary supply voltages are now finding application in high voltage tubes, although their use is at present limited to mercury filled tubes.

Cathode Characteristics

It may be well to give some attention to the meaning of the terms "cold cathode" and "hot cathode" as applied to fluorescent lamp electrodes. In Fig. 1 a typical specimen of each type may be compared. In general terms, a cold cathode usually takes the form of a hollow metal cylinder, of iron or nickel, for example, on which the discharge terminates and which, in operation, attains a temperature well below 200 deg. C. A hot cathode, on the other hand, usually

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† Communication from the Staff of the Research Laboratories of the General Electric Company, Ltd., Wembley, England.

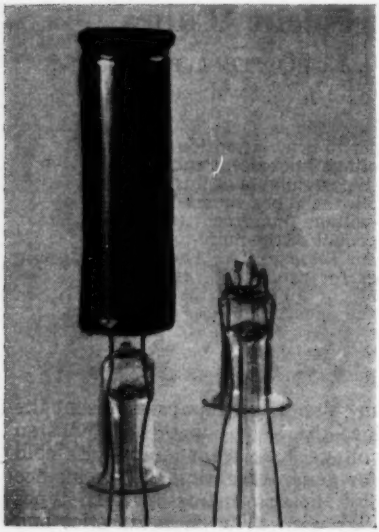


Fig. 1. Examples of cold and hot cathodes.

comprises a relatively small spiral of a refractory metal, such as tungsten, coated with an alkaline earth oxide or containing a pellet of oxide inside its turns. The working part of the spiral is maintained at a temperature in the region of 1,000 deg. C. during normal operation of the discharge.

In any stable discharge a stream of electrons continuously leaves the cathode and enters the discharge, and conditions at the discharge-cathode boundary adjust themselves to render this possible. A cold cathode is not a thermionic emitter in the usual sense of this term, and a relatively large amount of energy is required to extract an electron from its surface. In the cold cathode discharge there is a strong electric field represented by a steep fall in potential in the region of the cathode surface. Extraction of electrons from the cold metal is due in part to bombardment by positive ions accelerated in this potential gradient, and in part to field emission. The value of this "cathode fall," as it is called, is a function of the cathode material and gas filling as well as cathode current density. It is also dependent upon the cleanliness and prior treatment of the cathode surface. At values of the current met with in cold cathode lighting tubes, the cathode fall increases with increasing current density, so that cold cathodes are usually fairly large in relation to the tube current to keep the cathode fall at a reasonable value and to obtain a satisfactory tube life.

The emission of electrons is greatly assisted by the presence of such thermionically active metals as barium on a hot metallic surface. A hot cathode is a true thermionic emitter, in which the necessary heating is obtained either from the discharge itself or from an independent source. The cathode is maintained at its operating temperature partly by positive ion bombardment and partly by the heating effect of the discharge current. If independent heating is used the contribution of the positive ion heating is much reduced. It is probable that not all the electron emission from a hot cathode is thermionic; a fair proportion of the electrons may be released by positive ion bombardment and by field emission. The value of the cathode fall for practical hot cathodes is in the region of 15 volts compared with 150 to 200 volts for a plain iron cold cathode.

Much useful information concerning the behaviour of different types of cathode may be obtained by plotting the voltage—current characteristic of a discharge in which the positive column has been eliminated by bringing the electrodes close together. The voltage ordinate then approximates to the cathode fall over most of the characteristic. Fig. 2 shows such characteristics for four types of cathode having similar operating currents—two cold and two hot types. Curve (a) is for a cold cathode of plain metal. In tracing its characteristic the region between zero voltage and the "starting" voltage is not shown; this current is due to residual ionisation and is quite negligible. During this stage no visible glow appears in the tube. At the starting voltage

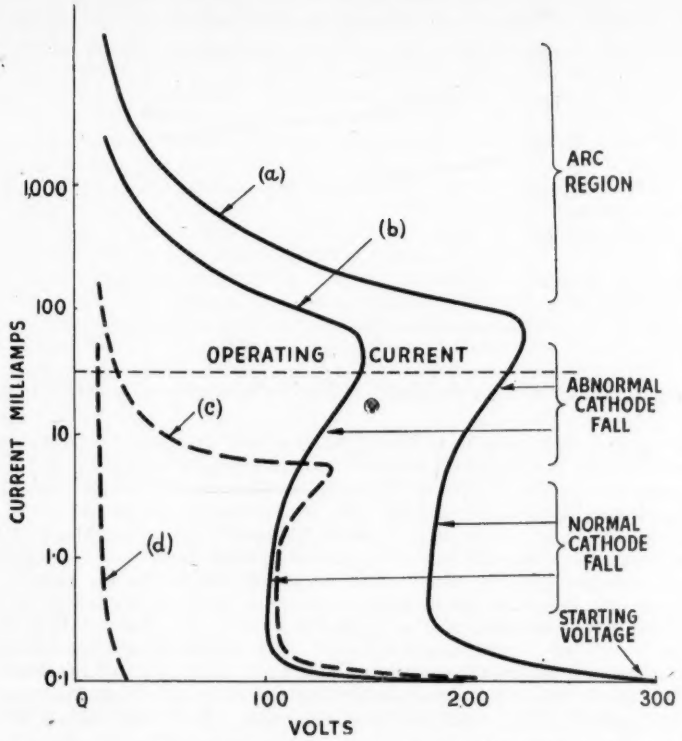


Fig. 2. Voltage-current characteristics for different cathodes. (a) Plain cold cathode. (b) Activated cold cathode. (c) Discharge-heated hot cathode. (d) Independently heated hot cathode.

an appreciable current begins to flow and a faint visible glow appears; thereafter the characteristic is strongly negative as the space between anode and cathode fills with glow. Over the region of "normal" cathode fall, the glow is spreading over the cathode with increase of current and the voltage remains substantially constant. When the cathode is completely covered, further increase in current leads to an increase in cathode fall and the characteristic becomes positive. This is the region of "abnormal" cathode fall.

As the current density at the cathode surface continues to increase, considerable heating of the electrode takes place. Further increase in current eventually leads to the formation of one or more "hot spots" on the cathode which begins to emit electrons thermionically. This effect is cumulative and the discharge passes over into the arc stage. The characteristic again becomes strongly negative, the cathode fall decreasing to a value comparable with the ionisation potential of the filling gas. This type of cathode usually operates on the abnormal region of the characteristic and is not intended to work under arc conditions; if permitted to do so, the intense positive ion bombardment neces-

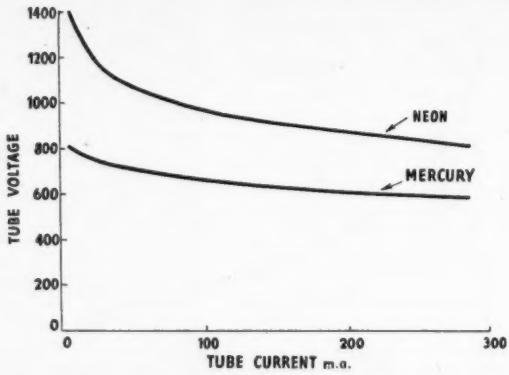
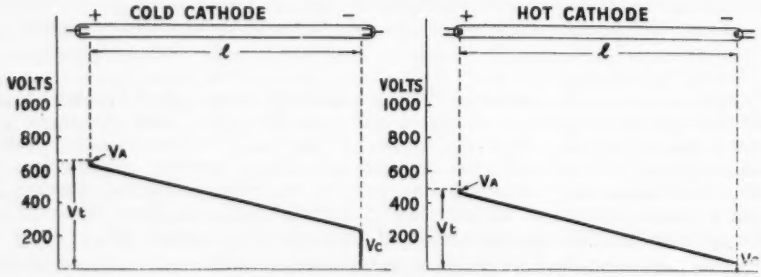


Fig. 3. Voltage-current characteristics of 9-ft. 20-mm. mercury and neon filled tubes.

sary to bring the cathode up to the thermionically emitting temperature causes disintegration of the electrode and the tube is rapidly destroyed.

If now the surface of the plain metallic cathode just considered is coated with an electron emitting material such as barium or one of the alkali metals the characteristic shown in Fig. 2 (b) is obtained. Here the starting voltage and cathode fall over the normal and abnormal regions are considerably reduced, but the general shape remains much the same as before. These advantages are, however, largely neutralised in practice, particularly in mercury filled tubes, because of the tendency of the emissive coating on cold cathodes to spread throughout the tube. This affects lumen maintenance of lighting tubes adversely and gives rise to erratic electrical and life characteristics. For these reasons plain, unactivated cathodes are frequently preferred for mercury filled tubes, despite their larger size. Activated cold cathodes can



$$Vt = IV + (Vc + VA) = IV + Ve.$$

V = Voltage drop per foot of positive column = 50 volts per foot.

For typical cold cathode Ve = 195 + 5 = 200 volts.

For typical hot cathode Ve = 15 + 5 = 20 volts.

Hence for 9-ft. cold cathode tube $Vt = 9 \times 50 + 200 = 650$ volts, and for 9-ft. hot cathode tube $Vt = 9 \times 50 + 20 = 470$ volts.

Fig. 4. Distribution of voltage along similar cold and hot cathode mercury-filled lighting tubes.

be operated at higher current density than the unactivated type, but must not work on the arc part of the characteristic for the reasons mentioned above.

Fig. 2 (c) shows the characteristic for a hot cathode of the type used without independent preheating at starting and which is maintained at its operating temperature by the discharge. The lower portion of the characteristic follows roughly curve (b) for the activated cold cathode, and it is interesting to note that no reduction in starting voltage is obtained, although the running voltage of the tube is less due to the lower cathode fall. Owing to the small area and low thermal capacity of the hot cathode, the normal and abnormal cathode fall regions occur over a much shorter current range and the arc condition is reached within a small fraction of a second. Only a relatively small amount of positive ion energy is needed to keep the cathode at its optimum temperature, which therefore operates in the arc condition without disintegration. Fig. 2 (d) gives the characteristic for a cathode heated independently of the discharge; the cathode is held in a highly emissive condition, whatever the value of the discharge current. The starting voltage is considerably lower than when the cathode is started cold, and the normal and abnormal cathode fall regions are absent from the curve. The low cathode fall is thus reached at comparatively low discharge currents.

In practical discharge lamps having a relatively long positive column or light-giving portion, the operating tube voltage is the sum of the cathode, anode and positive column voltage falls. The anode fall of voltage is small and is generally included with the cathode fall. In a long positive column discharge the negative characteristic of the positive column submerges the cathode characteristic and even when conditions are arranged so that the cathode is working on the positive part of its curve the overall characteristic is essentially negative. Fig. 3 shows the negative nature of the voltage current characteristics of 9-ft. mercury and neon filled lighting tubes of the type discussed later. Fig. 4 shows the distribution of voltage along two long positive column fluorescent tubes identical except that one has cold and the other hot cathodes. The tube voltage of the cold cathode tube is greater than that of the hot cathode tube by the difference in cathode falls of voltage. The inverse ratio of the tube voltages gives the ratio of their luminous efficiencies since both tubes are taking the same current and giving the same light output.

It is easy to show that in these conditions the luminous efficiency, L/W, is given by the expression

$$\frac{L}{W} = \frac{al}{Ve + bl}$$

where l is the length of the positive column, Ve is the cathode fall and a and b are constants the values of which depend on the type of tube under consideration.

Fig. 5 shows the general shape of the curve of L/W plotted against Ve for two similar positive column tubes of lighting length 9 ft. and 3 ft. respectively. These curves show that to achieve an efficiency of 45 L/W with a cold cathode (Ve = 200 V) the length of the particular type of tube under consideration must be not less than 9 ft. The same efficiency can be achieved with hot cathodes (Ve = 20 V) with a lighting length of about 3 ft. It is clear from the above that the efficiency of the luminous column is independent of the type of cathode used. It is, however, determined by other factors such as mercury vapour or neon pressure and current density which affect the production of ultra-violet radiation Mercury vapour pressure is a function of the tube

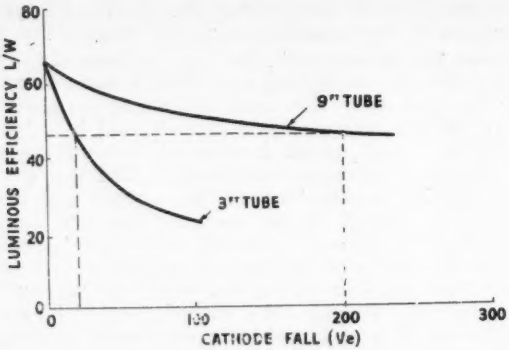


Fig. 5. Effect of cathode fall on the luminous efficiency of 20 mm. fluorescent tubes.

temperature which in turn depends on the tube loading. Fig. 6 shows the relation between efficiency and tube wall temperature or mercury vapour pressure, from which it is seen that the optimum efficiency is obtained at a wall temperature of 40 deg. C. With most types of low pressure fluorescent lamps burning in the open the lamps operate not far from the optimum temperature in normal ambient temperature conditions. It is possible, by modification to the rare gas filling, to ensure that the optimum efficiency is obtained at lower ambient temperatures. Thus, the addition of neon to the usual argon filling give better results outdoors or in cold situations because of the increased wattage dissipation per unit length of tubing.

Fig. 7 shows that the efficiency at constant mercury vapour pressure increases as the current density is reduced down to very low values. Reducing current density, however, reduces the loading and hence the mercury vapour pressure below the optimum value and the gain in efficiency cannot be achieved. In practice it is necessary to arrive at a suitable compromise between efficiency

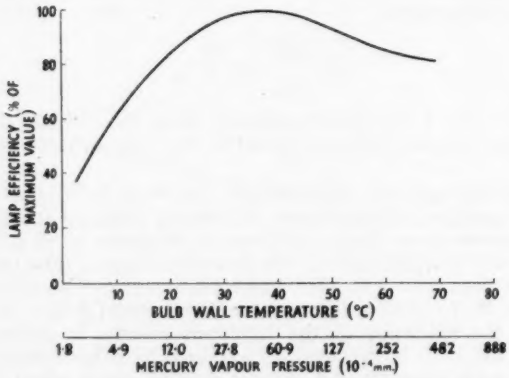


Fig. 6. Effect of mercury vapour pressure on the luminous efficiency of cold cathode fluorescent tubes.

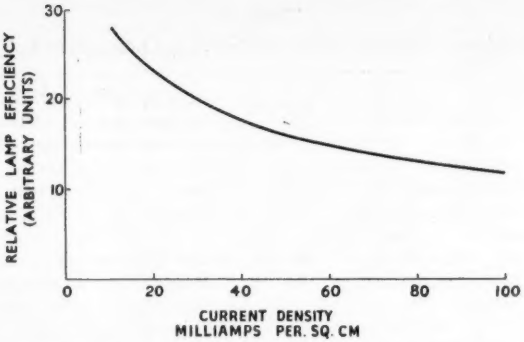


Fig. 7. Effect of current density on the luminous efficiency.

and tube loading which, of course, largely determines the light output from the tube. In neon-filled fluorescent tubes the same arguments apply except that temperature does not influence the position appreciably.

Luminescent Materials

Before discussing practical high voltage fluorescent lamps it may be well to say a few words on the important subject of luminescent materials. Luminescence, particularly from the point of view of its application to discharge lamps, has been the subject of various papers before the Society and elsewhere ([1-3]). It is intended in the present paper to refer only to those aspects of the subject which are of importance in high voltage tubes. Table I gives the chief phosphors in common use in low pressure mercury vapour and neon discharge lamps. These substances are prepared by firing the compound, or an intimate mixture of the appropriate constituents, together with the activating metal if one is used, at a temperature not far from 1,200 deg. C. for periods of from one hour to several hours according to the circumstances. The finished powder comprises crystalline particles a few microns in diameter. The luminescent characteristics of the phosphor are determined partly by the crystalline compound or matrix and partly by the activator.

The common characteristic of the phosphors in Table I is that they are all strongly excited by the mercury ultra-violet line at 2537A. In certain cases the excitation band extends down to very short wavelengths in the region of 700A which is just below the wavelength of strong ultra-violet lines in the neon discharge. In 1935 Jenkins ([4, 5]) found that zinc orthosilicate and calcium tungstate could be strongly excited by a discharge in pure neon. The neon lines chiefly responsible for exciting the luminescence are the series of resonance lines commencing at 735 and 744A. These lines represent only about 10 per cent. of the total radiated energy from the neon positive column compared with about 50 per cent. for the 2537A resonance line of mercury. Furthermore, the efficiency of transformation of the neon resonance radiation into visible radiation is only about 30 per cent. of that of mercury resonance lines so that the step-up in luminous efficiency with neon is small compared with that of mercury. On the other hand, the high initial efficiencies of coated mercury tubes falls off to some extent during life which is not the case with properly processed neon fluorescent tubes. Their average efficiency throughout life compares well

Table I.

Phosphors in Common Use in High Voltage Fluorescent Tubes.

Name	Chemical Formula	Activator	Colour of Fluorescence	Resultant Colour in	
				Mercury	Neon
Cadmium Borate	$Cd_2B_2O_5$	Mn.	Red	Cerise	—
Cadmium Chlorophosphate	$3Cd_3(PO_4)_2 \cdot 1CdCl_2$	Mn.	Orange	Apricot	—
Calcium Halophosphate	$3Ca_3(PO_4)_2 \cdot 1Ca(F, Cl)_2$	Sb. Mn.	Pale Blue to Orange-Red, including White Colours	Pale Blue to Orange-Red, including White Colours	—
Calcium Tungstate	$CaWO_4$	—	Blue	Deep Blue	Pink
Magnesium Tungstate	$MgWO_4$	—	Pale Blue	Sky Blue	—
Zinc Beryllium Silicate	$(Zn,Be)_2SiO_4$	Mn.	Greenish Yellow to Red	Various shades of off-white and pink	—
Zinc Silicate ...	Zn_2SiO_4	Mn.	Green	Bright Green	Gold

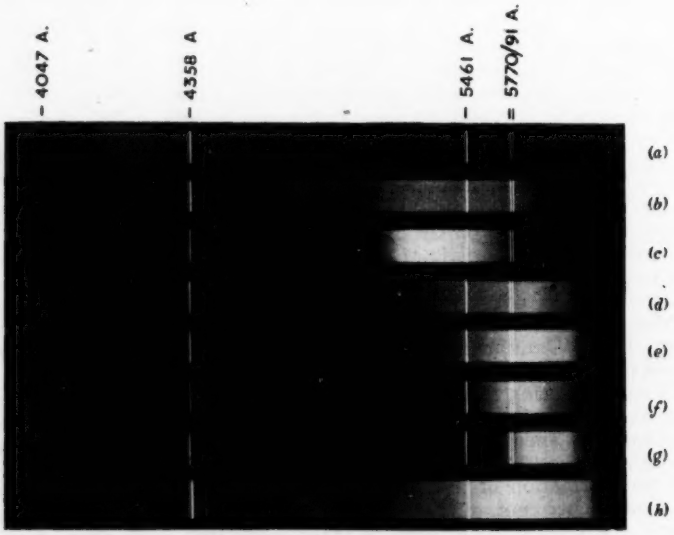


Fig. 8. Spectra of phosphors in common use in high voltage fluorescent tubes

(*a*) Cadmium tungstate, (*b*) magnesium tungstate, (*c*) zinc silicate, (*d*) and (*e*) zinc beryllium silicate, (*f*) cadmium chlorophosphate, (*g*) cadmium borate, (*h*) calcium halophosphate.

with that of mercury filled tubes, particularly when account is taken of the spectral quality of the light emitted. The full lumen maintenance and the abundance of red light in neon fluorescent tubes are of great importance for interior lighting.

The emission spectra of the phosphors in Table I. comprise fairly broad bands of wavelengths in the visible spectrum as shown in Fig. 8. The light from each phosphor is generally markedly coloured and to obtain a spectral composition suitable for general lighting it has been necessary in the past to mix the light from two or more phosphors. Sometimes this is done, as in the early high voltage tubes, by coating tubes with the individual phosphors and mixing the light from two or more differently coloured tubes. The more usual practice, introduced shortly before the war, is to mix the component powders in a single tube in proportions to give light of the required spectral composition. The mixed powders are milled together to form a paint-like suspension in a fairly viscous nitrocellulose solution. This is forced into the tube by compressed air and allowed to drain away. The resultant coating is baked at about 500 deg. C. to remove the organic binder.

An important discovery by McKeag and Ranby (3, 6) of a new series of phosphors, of alkaline earth halophosphate composition, has made it possible for the first time to obtain white light from a single phosphor. By varying the composition of the matrix, the amount of activators present and the method of manufacture, a range of colours from pale blue to pink and orange and including white colours can be prepared. The range of colours should prove of considerable value for producing coloured light both directly and in association with suitable filters for decorative lighting and advertising when conditions return to normal. The white colours emit broad bands of light covering the whole visible spectrum as shown in the typical spectro-

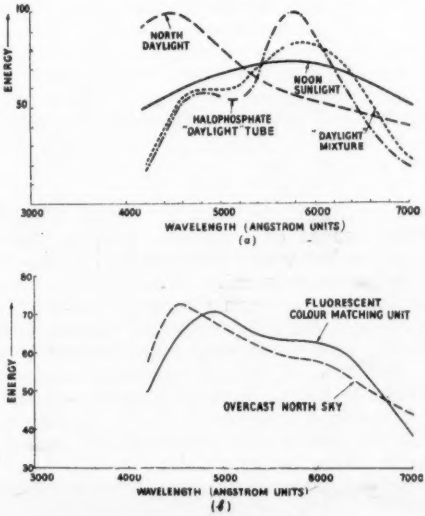


Fig. 9. (*a*) Spectral energy curves of "daylight" fluorescent sources and two phases of natural daylight. (*b*) Spectral energy curves of cold cathode fluorescent colour matching unit and overcast north sky.

gram in Fig. 8. Fig. 9 (a) shows spectral energy distribution curves of fluorescent sources giving light of "daylight" quality, obtained from mixed powders and calcium halophosphate respectively. Curves for two phases of natural daylight, noon sunlight and north daylight, are included for comparison. These and other spectral energy curves given in the present paper are all plotted on the basis of equal energy between the wavelength lines 4,200 A and 7,000 A; they are intended only for rough comparison of the spectral quality of the radiation emitted by the various sources discussed. The importance of these new phosphors goes far beyond their ability to give, without admixture with other phosphors, spectral distributions suitable for general lighting purposes. Apart from being highly efficient converters of ultra-violet into visible radiation, halophosphates possess remarkable stability to attack from excited mercury vapour in the discharge with consequent improved lumen maintenance during life.

High Voltage Fluorescent Tubes with Cold Cathodes

(a). Pre-war Practice

An account of high voltage fluorescent lighting as practised in this country before the war has already been published. (7) Developments in phosphors and improvements in technique have, of course, resulted in improved performance, but the austere conditions of the post-war period have restricted progress in other directions. Before discussing the present-day position a brief account of pre-war practice will be given.

Two types of straight standardised lighting lengths were used which differed only in detail from the present-day tubes shown in Fig. 13. The lower tube with the turned-back electrode chamber is for continuous runs of tubing where it is desired to avoid interruption of the line of light. Photometric characteristics of a number of pre-war lighting tubes are given in Table II. The efficiencies quoted are true initial values as was usual at the time; present-day practice is to give 100 hour and not true initial values.

As already mentioned, a range of white colours was obtained by mixing the light from differently coloured tubes. A typical pre-war lighting unit giving a daylight colour comprised a group of three standardised lighting lengths arranged side by side about 1 inch apart, the two outer tubes coated with a phosphor, such as zinc beryllium silicate, giving red and orange light, and the central tube coated with a powder, such as magnesium tungstate, giving blue light. It is interesting to note that these particular powders were subsequently to prove of vital importance for mains voltage fluorescent lamps. Another characteristic type of cold cathode lighting unit giving a daylight colour similar to the above but with better rendering of red colours, comprised two outer tubes coated with magnesium tungstate and a central tube using zinc orthosilicate excited by the neon discharge as described earlier. In the latter tube the green light from the fluorescent powder added to the red light from the neon discharge gave an attractive gold colour to the light as well as enhanced luminous efficiency. Calcium tungstate phosphor which fluoresces blue gives a pink colour in neon. A much warmer resultant light is obtained by using two neon fluorescent tubes in conjunction with a single magnesium tungstate tube. Fig. 10 shows the spectrum of the gold coloured neon fluorescent tube used in these lighting units.

A wide range of resultant colours from warm pink or orange tones for recreational lighting to colours of the daylight type for commercial and industrial lighting was obtained by the use of suitable combinations of the tubes listed in Table II. The overall wattage of these units is from 100 to 150 watts, the overall efficiency ranging between 20 and 30 L/W according

Table II.

Photometric Characteristics of Pre-War Cold Cathode Fluorescent Tubes.

Colour of Tube	Gas Filling	Tube Efficiency (Initial) L/W	Surface Brightness Stilb. (Tube current 60 m.a.)
Dark Green ...	Argon, Neon and Mercury	35	0.25
Bright Green ...	,,	55	0.40
Off-White ...	,,	25	0.18
Ivory White ...	,,	44	0.32
Deep Blue ...	,,	15	0.11
Peach	,,	27	0.19
Apricot	,,	30	0.22
Sky Blue ...	,,	30	0.22
Pink	Neon	15	0.14
Gold	,,	22	0.19

to the tubes employed. In addition to lighting units using straight standardised lengths, cold cathode tubes made in various curves and designs to conform with the architectural features of interiors are frequently used. These "tailor made" lighting installations can be very effective both functionally and aesthetically. Before the last war these tubes were usually run from leakage reactance transformers, one transformer operating from four to six standard lengths in series or an equivalent length of tailor-made tubing. The open circuit voltage of the transformer sufficed to start the tubes instantaneously. The margin of voltage available ensured certain starting and operation even under adverse supply voltage conditions. Lives of the order of 20,000 hours were quite usual. Fig. 11 shows a typical example of a pre-war installation in a flower shop using straight standardised lengths. Fig. 12 shows triple colour indirect lighting in the lounge of R.M.S. Oranje, a typical example of a tailor-made installation.

(b). Post-war Practice

In the high voltage fluorescent lighting described above white colours were obtained by mixing the lights from mercury-filled tubes of different colours. It is an obvious step from mixed colour to single colour lighting in which the different powders are mixed together in the same coating. Such a step was, in fact, taken soon after the introduction of silicate and tungstate powders in 1936, but the technique of distributing the component powders evenly over long narrow tubes was not fully developed until a year or so later, and the

Fig. 10. Spectrum of gold neon fluorescent tube.

Fig. 11. Example of pre-war cold cathode fluorescent lighting in a florist's.

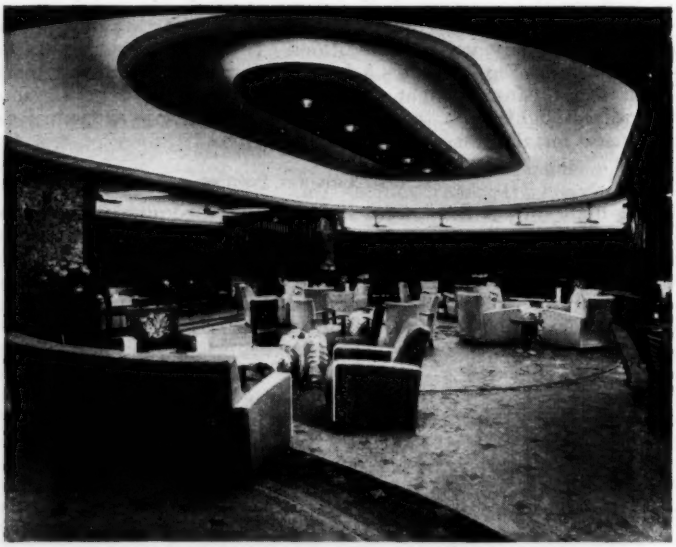
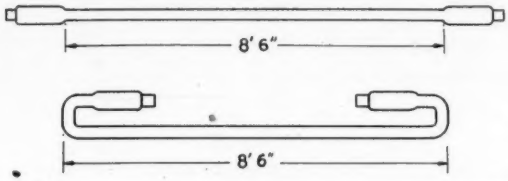


Fig. 12. Triple colour indirect lighting installation on R.M.S. Oranje using cold cathode fluorescent tubes.

use of single colour white tubes was confined to such applications as show case lighting and, occasionally, outdoor display.

The widespread use of mixed powder coatings in mains voltage lamps has naturally created a demand for similar colours in high voltage tubes, and the experience gained with mains operated lamps has been of the greatest value in overcoming the coating difficulties referred to above. Improvements in powders and lamp processing methods have made possible greatly improved efficiencies. The demand for increased light output from the tubing has been met by almost doubling the electrical loading of pre-war mercury tubes. Despite this greatly increased loading, lives of the order of 10,000 hours are readily achieved. The higher loading permits of much higher lumen output per unit length of tubing, which is an important consideration at the present time, but some of the advantages of low brightness are sacrificed. It is possible that when conditions return to normal the brightness factor may assume greater importance and lower current density operation may again be found desirable

Present-day standardised lengths are shown diagrammatically in Fig. 13



Filling	Dia. mm.	Current m.a.	Tube Voltage	Tube Watts
Argon and Mercury	20	120	650	70
Neon	20	60	1,040	56

Fig. 13. Dimensions and electrical characteristics of cold cathode fluorescent tubes.

together with their electrical characteristics. The latter differ somewhat from those of pre-war tubes due to changes in the gas filling and tube current. Table III gives photometric data relating to recent high voltage cold cathode tubes. As is now standard practice, the efficiencies at 100 hours are given rather than true initial values. The "Daylight" and "Warm White" colours are the same as the corresponding colours standardised for mains voltage fluorescent tubes in this country. "Intermediate White" is, as its name suggests, precisely intermediate in spectral energy distribution between the daylight and warm white colours. The electrical and photometric characteristics of modern neon filled tubes are substantially the same as for the pre-war tubes. The loading of these tubes cannot be materially increased without spoiling their colour.

The method of operation using leakage reactance transformers described above is still used for "tailor-made" lighting installations. Lighting units comprising three straight standardised lighting lengths are operated from two leakage reactance transformers connected in tandem, as shown in the circuit diagram in Fig. 14, a scheme introduced shortly before the last war. This double transformer method of operation is possibly more expensive than a single transformer, but their smaller size enables them to be placed inside end

Table III.

Photometric Characteristics of Recent Cold Cathode Fluorescent Tubes.

Colour of Tube	Gas Filling	Tube Efficiency (100 hours) L/W	Tube Efficiency (Average over 10,000 hours) L/W	Surface Brightness (100 hours) (Tube current 60 m.a.) Stilb.
Bright Green ...	Argon and Mercury	64	46	0.47
Ivory White ...	,,	44	31	0.32
Deep Blue ...	,,	16	10	0.12
Sky Blue ...	,,	31	22	0.23
Cerise	,,	28	18	0.20
Gold	Neon	20	20	0.17
Daylight ...	Argon and Mercury	40	31	0.29
Intermediate White	,,	40	31	0.29
Warm White ...	,,	40	31	0.29

Table IV.

Technical Data for Daylight, Intermediate White and Warm White Triple Tube Units.

Overall length of unit	9 ft. $10\frac{1}{4}$ in.
,, ,, ,, tubes	9 ft. 6 in. $\pm$ $1\frac{1}{4}$ in.
Visible ,, ,, ,, ...	8 ft. 6 in.
Diameter of tubes	20 mm.
Tube current	120 m.a.
Efficiency of tubes at 100 hours	40 L/W.
,, ,, ,, Average over 10,000 hours ...	31 L/W.
,, ,, ,, at 10,000 hours	26 L/W.
Overall consumption of tubes	210 watts
,, ,, ,, unit	250 watts
Corrected power factor	0.85
Life	10,000 hours

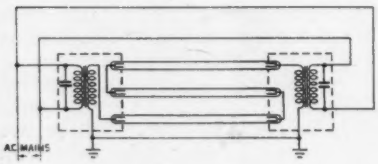


Fig. 14. Circuit diagram for triple tube cold cathode unit.

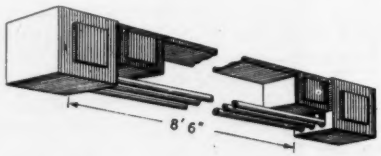


Fig. 15. General construction of self-contained cold cathode fluorescent lighting unit.

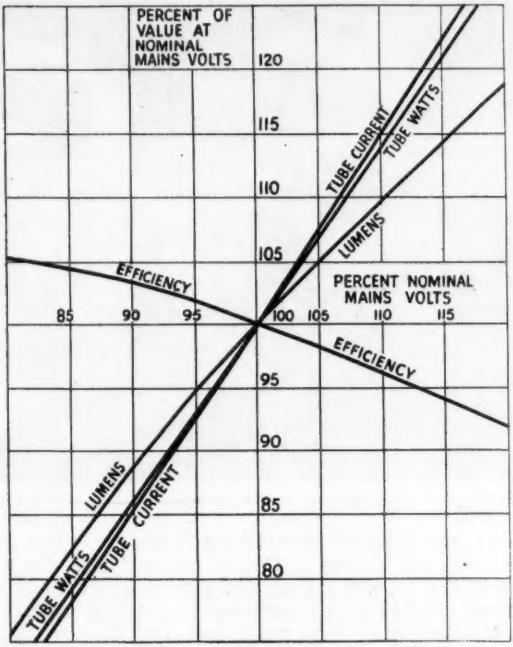


Fig. 16. Effect of mains voltage variation on characteristics of mercury filled cold cathode lighting tubes.

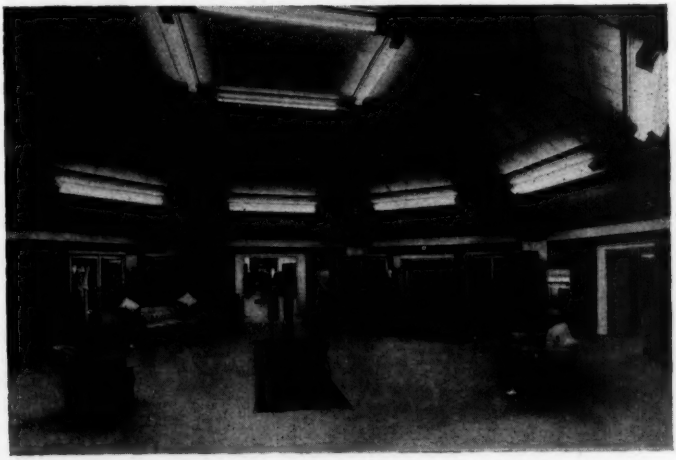


Fig. 17. Use of self-contained cold cathode fluorescent units in the rotunda of a large store.

Fig. 18. Lighting in a large store using self-contained cold cathode fluorescent units.

boxes which also house the tube electrodes and the capacitors for power factor correction. High tension wiring is thus eliminated and the unit is self-contained, as shown in Fig. 15, which gives the general construction of the unit.

Table IV gives electrical and photometric data for daylight, warm white and intermediate white triple tube units, and the diagram in Fig. 16 shows the effect of variation of mains voltage on the more important of these charac-

Fig. 19. A modern " tailor-made " cold cathode fluorescent installation in a hotel.

teristics. The form of these units can be seen in the examples of space lighting in a large store shown in Figs. 17 and 18. A detail of a recent "tailor-made" installation in a hotel is shown in Fig. 19.

A different application of cold cathode fluorescent tubes is to critical industrial colour matching. Fig. 20 shows a high voltage fluorescent colour matching unit recently introduced in this country. Fig. 9 (b) shows the spectral energy distribution of the light, which closely corresponds to that of an overcast north sky, and which was finally settled after consultation with important users in various branches of industry. The good lumen maintenance characteristic of plain unactivated cold cathodes is of great importance for this application, because it leads to constancy of colour rendering throughout life. Cold cathodes also permit of low tube loading, which contributes to the same end. Uniformity of colour rendering from tube to tube, which is, of course, particularly important in colour matching, is achieved by special care and individual testing of every tube during manufacture. Table V gives the relevant technical data for the colour matching unit.

Table V.

Technical Data for Cold Cathode Fluorescent Colour Matching Unit.

Overall length of fitting	6 ft. 6 in.
Overall width of fitting	10 in.
Visible length of tubes	4 ft. 8 in.
Diameter of tubes	20 mm.
Tube current	90 m.a.
Overall consumption of tubes	70 watts
Overall consumption of unit	90 watts
Corrected power factor	0.85
Average illumination on horizontal plane, 3 ft. below fitting over an area of 4 ft. long by 2 ft. wide	50 lumens per sq. ft.
Life	10,000 hours*

* Due to slight colour depreciation during life, the effective life may be less than this figure, according to the degree of accuracy required.

The Production of Very Warm Light

It is common practice even with a source as rich in red light as is the tungsten lamp to increase the warmth of the light by using pink or amber tinted fittings, despite the considerable loss in efficiency which results. It is, of course, possible to increase the warmth of the light of mercury-filled fluorescent lamps by adjusting the composition of the fluorescent coating. Unfortunately, deep red light cannot be added without serious loss of efficiency; also, as the blue fluorescent light is decreased, the purple colour rendering characteristic of the mercury lines at 4047 and 4358A becomes pronounced. The present mercury warm white colour probably represents as good a compromise between warmth of colour and efficiency as is possible at the present time with this type of source. Fig. 21 (b) shows the spectral energy distribution curves of mercury filled warm white and tungsten sources. It will be seen that the tungsten source is much richer in deep red radiation than the discharge source.

For many fluorescent lighting applications, in restaurants, for example, a

Fig. 20. Cold cathode fluorescent colour matching unit.

light warmer than the present mercury filled warm white is sometimes needed giving good rendering of deep red colours without too much purple distortion of blue colours. Neon fluorescent tubes in combination with ordinary mercury filled white tubes can be used very effectively for such applications. The neon discharge provides the deep red radiation which is desirable for rendering the colour of the human skin in a pleasing manner. Table VI, columns (a) and (b), gives technical data for two modern triple tube mixed colour units comprising two intermediate white tubes in association with a central neon fluorescent tube. In (b) the ratio of neon to mercury fluorescent light is higher, giving a warmer resultant colour. Spectral energy distribution curves

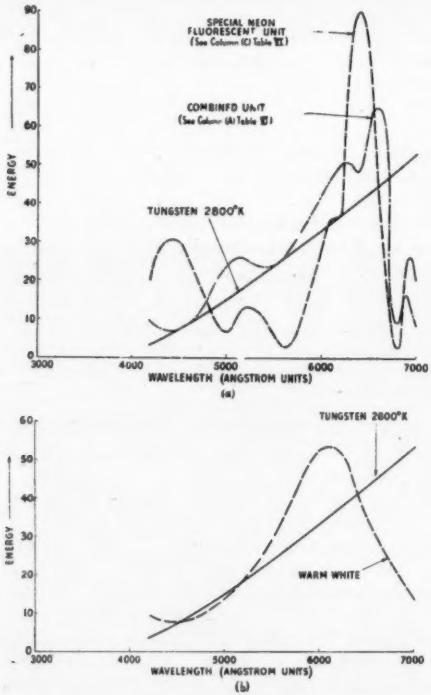


Fig. 21. (*a*) Spectral energy curves of cold cathode fluorescent lighting unit using neon fluorescent tubes.

(*b*) Spectral energy curves of mercury filled warm white fluorescent tube and tungsten filament lamp.

of the light from the colder of these units together with those of other warm sources are shown in Fig. 21 (a). By using daylight or warm white tubes in place of the intermediate white colour a range of spectral distributions can be obtained at sensibly the same efficiency. As mentioned earlier, the light output of neon fluorescent tubes does not depreciate during life, as happens with mercury-filled tubes. This gives rise to a slight change in the composition of the light from these units as the tubes get older, the tendency being for the light to become slightly warmer. Experience has shown that this change is unimportant in practice.

Table VI.

Technical Data for High Voltage Lighting Units Incorporating Neon Fluorescent Tubes.

	(a) Two mercury filled white* tubes at 120 m.a. One neon gold tube at 60 m.a.	(b) Two mercury filled white* tubes at 80 m.a. One neon gold tube at 60 m.a.	(c) Triple tube unit with special neon fluorescent tubes	(d) One ivory white tube at 120 m.a. One neon gold tube at 60 m.a.
Overall length of unit ...	9 ft. 10¼ in.	9 ft. 10¼ in.	9 ft. 10¼ in.	—
,, ,, ,, tubes	9 ft. 6 in. ±1¼ in.	9 ft. 6 in. ±1¼ in.	9 ft. 6 in. ±1¼ in.	8 ft. 6 in.
Visible ,, ,, ,, ...	8 ft. 6 in.	8 ft. 6 in.	8 ft. 6 in.	8 ft. 6 in.
Diameter of tubes ...	20 mm.	20 mm.	20 mm.	20 mm.
Tube current. Mercury filled	120 m.a.	80 m.a.	—	120 m.a.
Tube current. Neon filled	60 m.a.	60 m.a.	60 m.a.	60 m.a.
Combined tube efficiency at 100 hours	33.0 L/W.	32.0 L/W.	17.5 L/W.	33.5 L/W.
Combined tube efficiency Average over 10,000 hours	27.5 L/W.	26.0 L/W.	17.5 L/W.	26.0 L/W.
Combined tube efficiency at 10,000 hours	24.0 L/W.	23.0 L/W.	17.5 L/W.	21.0 L/W.
Overall consumption of tubes	196 watts	148 watts	168 watts	126 watts
Overall consumption of unit	236 watts	180 watts	202 watts	150 watts
Corrected power factor ...	0.85	0.85	0.85	0.85
Life	10,000 hours	10,000 hours	Data not available	10,000 hours

* Daylight, Intermediate White or Warm White.

Attractive warm lighting effects can be obtained by using neon fluorescent tubes as decorative features in tungsten or mercury fluorescent lighting schemes. The efficiency is some four or five times that of filtered tungsten light of the same general quality. With either type of source the distortion of blue colours, which tend to look bright green under the discharge source and dark green under the filtered tungsten, is very marked. Owing to this blue deficiency the

differences in the colour rendering of the subtler shades of red are not brought out; this, combined with the distortion of blue colours, makes these sources hardly suitable for use alone. These defects have been overcome to some extent without affecting the amount of red light emitted, in a new type of neon fluorescent tube using a fluorescent coating emitting blue as well as green light. The colour appearance of the tube is salmon pink, and the colour rendering of blue colours is greatly improved. The rendering of red colours in the subjective sense is also better than that of the gold tube alone for the reasons mentioned above. Sources of this type are still under development and have not been used except in experimental lighting installations. They may possibly find application where very warm lighting is required. The spectral energy distribution of the light is shown in Fig. 21 (a). Technical data for a triple tube unit are given in Table VI, column (c)

The importance of the careful choice of colour in decorating interiors is not fully appreciated, and perhaps not enough attention has been paid by illumination engineers to the possibility of coloured lighting. Cold cathode fluorescent tubes, because of the wide range of coloured sources available and other special characteristics, are peculiarly adapted to the more colourful and decorative forms of lighting. One of the most pleasing and effective ways of employing coloured lighting is by means of high voltage fluorescent tubing in well-designed coves. Both standardised lengths and tailor-made tubing can be used in this way. A wide range of effects can be obtained in an indirect triple-colour lighting system, in which the intensity of the light from the individual colours can be varied. This is usually done by resistive or saturated-choke control of the supply feeding the transformers. Mercury-filled tubes may readily be dimmed to 5 per cent. of their maximum intensity or less, but neon-filled tubes are not usually taken below about 10 per cent. because of the tendency to flicker at very low currents.

It is sometimes required to reproduce the colour appearance of ordinary tungsten light reflected from coves or ceilings in indirect lighting schemes. It is difficult, if not impossible, to do this satisfactorily with any of the ordinary mercury-filled fluorescent tubes even with specially treated reflecting surfaces. It can, however, be done effectively with normal coves and ceilings by means of gold-coloured neon fluorescent tubing in combination with a mercury-filled tube using a special phosphor. Technical data relating to this combination of tubes are given in Table VI, column (d).

High-Voltage Hot Cathode Fluorescent Tubes

It might be asked why cold cathodes are used for high-voltage fluorescent tubes rather than the more compact hot cathodes with their lower cathode losses. Cold cathodes possess a number of advantages not the least of which are their inherently longer life and good lumen maintenance and instant starting characteristics. The lamp life is independent of the number of times the lamp is switched, and can be achieved with a relatively narrow spread from tube to tube. These are important factors when the replacement problems associated with long narrow tubes are considered. Other advantages are the ability of cold cathodes to operate at any current lower than the maximum for which they are designed, which facilitates dimming and low brightness operation. A wide range of colours and effects through the use of neon fluorescent tubes also becomes available. Because of their high cathode fall of potential, cold cathode tubes are, however, necessarily

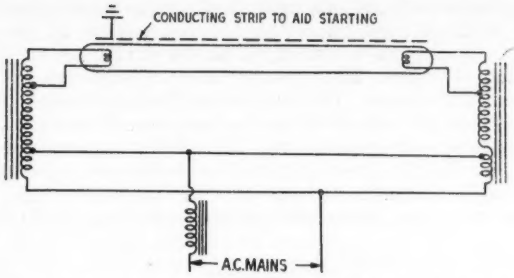


Fig. 22. Circuit diagram of experimental hot cathode high voltage lighting unit.

designed to operate at as high a voltage as is practicable to obtain satisfactory efficiency; short tubes or large diameter tubes with cold cathodes are not, therefore, very practicable. Hot cathodes, because of their low cathode fall, are not subject to this restriction, and enable reasonable efficiencies to be achieved in such tubes. This characteristic of hot cathodes, and their compactness, are considerable advantages.

Before the war the present authors developed and used in experimental lighting installations hot cathode fluorescent tubes the same length as the standard cold cathode tube but 30 mm. in diameter. Each tube was operated from two auto-transformers in tandem with cathode heating windings as shown in Fig. 22. Electrical and photometric data for a single tube of this type are given in Table VII. The efficiency figure refers to present-day phosphors. The difference in potential between the transformers is insufficient to start the discharge until the cathodes reach their emitting temperature. This prevents cold starting and leads to economy in the design of transformers and to a higher uncorrected power factor. An external aquadag or other conducting strip along the length of the tube further facilitates starting and is useful with this type of circuit under adverse supply voltage conditions. The war, and difficulties arising out of it, have inevitably delayed the introduction of long hot cathode tubes of this type, but there seems little doubt that such tubes will be available in the reasonably near future and will find considerable application where luminous efficiency, rather than long life and flexibility in operation, is the overriding requirement.

TABLE VII.

Electrical and Photometric characteristics of pre-war long hot cathode fluorescent tube.

Length	Diam.	Current	Voltage	Watts	Efficiency (100 hours)
8 ft. 6 in.	30 mm.	300 ma.	250	68	50 L/W.

More recently a range of long narrow fluorescent tubes with hot cathodes has become available in the States(7). In these tubes the cathodes are not independently heated, but are specially designed to withstand cold starting. The discharge maintains them at the correct operating temperature once the

arc has formed. This system has the advantage of simplicity of wiring since only one wire goes to each cathode instead of two, as with independently heated cathodes. The ratio of open circuit to running voltage of the transformer is necessarily higher, and the uncorrected power factor lower than with independently heated cathodes. High power factor is achieved by the use of two tubes in a split-phase circuit. Only mercury filled fluorescent tubes are available and, as might be expected, efficiencies are some 25 per cent. to 30 per cent. higher than obtained with cold cathode tubes. Lives are stated to be from 2,500 to 6,000 hours, according to the number of times the tubes are switched. Apart from commercial information given by the manufacturers, few technical articles dealing with the tubes themselves have appeared in the technical literature.

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Discussion

MR. H. R. RUFF said that to him the excellent paper brought back memories of the entry of neon signs into the artistic lighting field. The change which, as had been indicated by the authors, had been made possible by the advent of fluorescent powders, was beginning to become apparent in 1938 and 1939. However, judging from the lantern slides of recent installations, he differed strongly from the authors when considering the merits of different types of high-voltage lighting. He had always considered that the finest tribute to a lighting installation was when after being in a room for some time a visitor, asked for his opinion of the lighting, had to look round before being able to make any comments. In other words, the lighting had been so effective that it had not seemed to be artificial. Directly visible lamps were introduced, the effect was slightly reduced, and if the visible lamps were of different colours the effect was to him definitely spoilt. He believed the first high voltage lighting installation using white light tubes was in a cinema in Leicester-square in 1938. The authors' demonstration of the colour of light obtainable by using two tubes coated with zinc beryllium silicate and magnesium tungstate was most interesting, as this was closely the colour of the light in that installation. It was obtained by mixing these powders in about the same proportion for the lamp coatings. Mixed powder lamps were used for the sole interior lighting of a building early in 1939 at Edgbaston, Birmingham, and he believed that when the high-voltage lighting art had become stabilised, the majority of the lamps would be white light tubes.

The authors had gone into considerable detail with regard to the benefits which they considered were introduced by the use of multi-colour tubes, including neon, but from a wide range of practical tests he believed it was possible to get from a single tube, using a mercury vapour exciting discharge, as good a colour rendering as was obtainable by the addition of neon light as generally employed. It was difficult to carry out colour demonstrations in a lecture hall, and he sympathised with the authors whilst criticising their demonstrations.

It was true that, as they had shown, adding neon light to certain fluorescent lamps could give a better colour than adding cadmium borate light, but by using combinations of different powders it was possible to get quite different results, and it was necessary to sort out the colours very carefully under laboratory test conditions. There was an alternative way of adding even deeper red light, viz., using incandescent lamps in combination with fluorescent lamps, and it was probable that much store lighting in the future would be by a combination of large area lighting from white fluorescent tubes with spot lighting from incandescent lamps.

Since the war conditions had not permitted the expansion of artistic lighting, for which he considered the cold cathode high-voltage tube particularly suitable. It allowed the bulking of control gear, and with careful layouts the lamps could be used to form the lighting circuit with little high-voltage wiring. However, manufacturers had put in a great deal of effort to convert cold cathode lighting into a simpler form. Thus high-voltage lighting had taken on a "new look," with long skirts at the ends of the fittings to house high-voltage control gear. The length of these skirts could be reduced by using lower voltages if hot cathodes were used. These hot cathodes took less space and could supply larger currents, enabling one lamp of higher efficiency to take the place of two or three cold cathode tubes. It seemed to him that this formalised form of long lamp lighting would be largely taken over by hot cathode lamps.

Captain C. Higgins said he did not at all agree with the last speaker. At the present stage of the art, it was not practical to add sufficient red light in a single tube to overcome the effect of the blue light. As people get older the little capillaries in the face tend to rise to the surface, and when there is too much blue light it aggravates the ravages of time on the human countenance. The addition of red light is to endeavour to diminish this effect.

It is, he continued, most important that the various factors which control the colour of light be given careful consideration. In point of fact in restaurant lighting there are five factors which a lighting engineer has to consider, quite apart from the technical aspect of illuminating engineering design, and these are the effect of the colour of the light on:—

(a) the human face,
(b) the clothes worn by customers,
(c) the furniture, fittings, and hangings,
(d) food,
(e) paint on the walls and ceilings, etc.

It is not practical with one tube at the present time to satisfy all these points; that is the reason why the neon fluorescent tube is used to bring in the rich red portion of the spectrum.

A word of caution is necessary here. It is possible to overdo the admixture of red. If the light is too red, then the artifices of the beauty parlour are defeated, as the colours of both rouge and lipstick are seriously distorted. Fortunately there is a fairly wide tolerance in this admixture of red light, but it is desirable to attain as near as possible to the optimum.

The colour of paints used on walls and ceilings requires careful attention; the utmost havoc can be wrought to the most excellent lighting scheme if the walls and the ceilings are painted in colours unsuited to the colour of the light.

The advent of fluorescent tubes, he said, called for education of the public in

their use, and he hoped that the Illuminating Engineering Society would, during the next few years, do its best to deal with this in a suitable manner.

Mr. A. CUNNINGTON said that being a user he did not view these problems with quite the same optimism that the producer and seller did! The seller spoke of the good features but showed a slight, though very natural, reticence about any points that might be a little troublesome. He had after a good many years' experience tried to anticipate the troubles that might be likely to arise, then to put these to the seller so that as far as possible they might be avoided.

The point that appealed to him most about the cold cathode lamp was, naturally, the long life which was an important feature, especially where frequent replacements might be costly. However satisfactory the electrical features in an industrial lighting installation, there was always, of course, the difficulty of keeping lamps and fittings clean and this was quite enough trouble without adding to the cost of maintenance by frequent replacements. Apart from the long life of the cold cathode tube and the advantage in some cases of the 9-ft. length, he could not see any reason for departing from 5-ft. tubes at ordinary voltage which had come into pretty general use.

He had noted with interest the examples of installations giving equivalent white light by combination of colours, but he thought they were limited in their application. It could not be said that he was biased because the Southern Railway in 1938 installed the first station lighting with cold cathode coloured tubes. The result was effective, but they would not at the present day perpetuate the coloured tubes, as ordinary white tubes were now just as effective and would reduce the number of types it was necessary to stock for replacement.

There was an important question with regard to the life of these lamps. The life of the tubes had been mentioned as 10,000 hours, and it might be that it would be longer, but would the rest of the apparatus have an equally long life? Would the whole equipment remain working satisfactorily during the same period or was there any other portion of it that was likely to fail earlier? He did not suppose there was much to go wrong, but he would like to be assured on that point.

Speaking generally, he rather deprecated a tendency to treat fluorescent lighting as if it was suitable for universal application. It was still perfectly reasonable to use ordinary tungsten lighting for a great many purposes. It was efficient enough and was very simply and cheaply installed. If one had to pay something like £30 for a triple cold cathode tubular fitting one could see that a large saving in capital expenditure would be effected by installing an equivalent tungsten installation. At the present time there seems to be a tendency to regard fluorescent lighting as essential in order not to be behind the times and he knew of cases where people in offices had a first-class tungsten installation but were annoyed because they thought they had not got the latest thing.

He associated himself with one remark made by Mr. Ruff, viz., that a lighting system should not obtrude itself. That was one of the greatest advantages of fluorescent lighting. There had recently been installed some cold cathode tubes in the booking hall at Hastings, mainly to light some murals there. The general effect on the walls was very good and one did not feel conscious of the source of the lighting. The whole place glowed with light, which was in sharp contrast with some of the earlier installations.

He was much interested in many of the examples of decorative lighting with 9-ft. tubes which had been shown on the screen and which seemed to fit admirably into the architectural scheme. All that now seemed necessary was

to see that architects in the future designed all their cornices and panels in multiples of 9 ft.!

MR. C. R. BICKNELL joined issue with Mr. Jenkins in his claim that an advantage of the cold cathode system was the practicability of the series operation of a number of tubes in conjunction with a single set of control gear. That was very nice as long as all the tubes were operating satisfactorily, but in the normal course of events tube failures must occur and the failure of a single tube would cause all those in series with it to fail also and thus affect a relatively large area until the faulty tube was located and replaced—not a simple operation.

The authors stated that the average efficiency of cold cathode neon-filled tubes throughout life compares well with that of mercury-filled tubes, particularly when account is taken of the spectral quality of the light emitted. He did not understand that statement; surely the comparison of the relative efficiencies of light sources was not influenced in any way by the spectral quality of the light emitted by them.

MR. J. MORTIMER HAWKINS inquired as to what provision was made on either high-voltage or mains-voltage fluorescent lighting for earth leakage protection. The provision of earthing and bonding wires in a fitting or electrical installation does not provide the security that might, on the face of it, be thought to exist.

Surely, the reactance in series with the tube limits the current under fault conditions, so that its value seldom rises above 30 per cent. in excess of the normal working figure. The maximum current which a fuse wire is capable of carrying continuously is no more than half the fusing current, and it would, therefore, seem that the fuseboard associated with fluorescent lighting installations can claim little more than ornamental value, and has practically no functional purpose. Not only is the fire risk arising from this considerable, but every installation of this kind put in increases the fire hazard, and the consumer is allowed to go on in blissful ignorance.

Surely, he said, no reason could be adduced to justify the continuance of such procedure, and he would very much like to see serious attention and thought given to liquidating this unsatisfactory position.

MR. E. G. PERNET remarked that everybody seemed to be thinking in terms of foot-candles or lumen efficiency, but he did not think that was the way to deal with this new lighting medium. The authors had mentioned cove lighting and had shown some examples of how this new form of lighting with slow colour change could be used in that connection, and it seemed to him that this representative gathering of lighting engineers by their applause was greatly impressed by the display. When indirect lighting was first introduced, lighting engineers said it was bad because it was static. He thought there must be gradual motion as there was in daylight effected by the clouds passing over the sun. With the advent of 5-ft. tubes and now the newer 9-ft. tubes, he thought the whole matter was a question of design and must be regarded as an art and treated as such, otherwise they would all be labouring with foot-candles and lumens for the rest of their lives.

MR. S. S. BEGGS referred to the authors' demonstration of matching tungsten

lighting with tube lighting, and asked how the tubes compared with warm white.

THE PRESIDENT asked for a little more information with regard to the efficiency of these tubes when they were dimmed, and for some details of the way in which the dimming was effected.

Referring to the very much longer life that had been mentioned, he said that looking upon these things from the point of view of a domestic user he was not very interested in a life of 10,000 hours. This suggested that the lamps would linger on for 10 years, and he was not at all sure that lamps in 10 years' time would look in the least like present-day lamps. Even in the case of a factory working a 40-hour week the life would be a matter of five years, but personally he was all for a short life and a gay one as far as lamps were concerned. He would be much happier with 50 per cent. more efficiency for 1,000 hours than the efficiency the authors had claimed for a life 10 times as long.

In their reply, THE AUTHORS agreed with Mr. Ruff that in a good lighting installation the source should be unobtrusive. They could not, however, agree that this applied more to mixed colour lighting than to single colour sources. Indeed, it could be argued that if the light source is to be seen there is a case for having it multi-coloured and interesting; however, in their view, indirect lighting was, in general, the most effective. The authors were well aware of the various methods of improving the red rendering of mercury-filled fluorescent lamps and had referred to these in the paper. The somewhat obvious device of using tungsten lamps to make up for the deficiency in red of mercury fluorescent lamps could hardly be regarded as a solution to the problem: apart from the comparative inefficiency of the method, the sizes of the two sources were quite incompatible. On the question of end boxes, these could obviously be made much smaller by housing the gear apart from the fitting, and this was the usual practice.

The authors suggested that despite Mr. Higgins's remarks young people were just as keen on good lighting as their elders. They agreed with him that care must be exercised in using very warm sources where it is important to show make-up to the best advantage. It was interesting to note that the colour of room decorations was much less affected by mixed colour lighting than by mercury fluorescent tubes; decorations designed for tungsten lighting were generally quite acceptable with mixed colour lighting.

In reply to the next speaker, the authors had little to add to the information contained in the paper. They repeated their view that high-voltage hot cathode tubes have their own field of application, and will certainly find considerable application where luminous efficiency is the over-riding requirement, rather than long life and flexibility in colour and in operation.

Replying to Mr. Cunnington's remark about the optimism of the producer and seller, the authors could not lay claim to belonging to either of these categories. They had done their best to give a balanced account of the subject It was possible that for the kind of lighting with which Mr. Cunnington was concerned, namely station lighting, the mercury-filled fluorescent tube was entirely adequate. They hoped, however, that the demonstrations had shown the value of mixed colour lighting for many other lighting applications. With regard to the life of the chokes and transformers there was nothing to suggest that the control gear would not survive many lamp lives even at 10,000-hour life per lamp. Installations were still in use with the original gear after more than 40,000 hours' operation. The authors agreed that the simple tungsten

filament lamp was likely to hold its own for a long time; the demand for fluorescent lighting continued to increase, however, and there was no doubt that fluorescent installations tended to make the usual tungsten lighting look dull and uninteresting.

Replying to Mr. Bicknell, the authors could not recollect stressing the advantage of series operation. Experience had, however, shown that series operation of these long-lived tubes did not give rise to trouble in practice. The authors held the view that a statement on relative luminous efficiency of different sources without some reference to the spectral quality of the light is almost meaningless. Thus green light obtained at, say, 100 lumens per watt might be of much less interest to illuminating engineers than light of a wider spectral energy distribution obtainable at a much lower efficiency.

Replying to Mr. Hawkins the authors agreed that an earth fault in a system using a current limiting device would not necessarily blow the fuse. This problem was common in a greater or lesser degree to practically all electrical circuits. Thus, in the ordinary tungsten filament lamp circuit, a fault in the return lead would cause arcing without blowing the fuse; no one seriously suggested that fuses in these circuits have merely an ornamental value. Unlike much electrical equipment in circuits where the same problem arises, fluorescent lamp control gear is designed to withstand fault conditions. Extensive experience both in England and in the United States had shown that the fire hazard from electric discharge installations is negligible.

Replying to Mr. Beggs, the authors said that the quality of the discharge light simulating tungsten light was very different from that of warm white fluorescent lamps. The efficiency of the former source is some 10 per cent lower than that of the warm white tubes.

Replying to the President, the authors stated that the efficiency of the tubes when dimmed depended on the method of dimming employed. Thus with saturated choke dimming there was little loss in efficiency. With resistive dimming, on the other hand, the efficiency rapidly decreased as the tubes were dimmed. It was questionable if high-voltage tubing would find much application in domestic lighting; the authors could not, however, see why a long life should not be acceptable to the domestic user. It was not very practicable to increase the efficiency of the lamps at the expense of life.

SESSIONAL MEETING IN LONDON

A Sessional Meeting was held at the Lighting Service Bureau, 2, Savoy-hill, W.C.2, at 6 p.m., on Tuesday, March 9, 1948, when the President (Dr. J. W. T. Walsh) took the chair. The minutes of the last meeting were taken as read and approved, and particulars of the next meeting were announced.

The President then called upon Mr. H. G. Jenkins to present the paper entitled, "High Voltage Fluorescent Tubes," by himself and Mr. J. N. Bowtell. The paper drew attention to some of the special characteristics of high voltage fluorescent tubes and made reference to the cold cathode tubes available in this country. The authors gave a number of interesting and instructive demonstrations and showed slides of a number of lighting installations using this type of fluorescent tube.

After a vote of thanks, proposed by the President, had been carried, the discussion was opened by Mr. H. R. Ruff, who was followed by Mr. C. Higgins, Mr. A. Cunnington, Mr. C. R. Bicknell, Mr. J. Mortimer Hawkins, Mr. E. G. Pernet, Mr. S. S. Beggs and Dr. J. W. T. Walsh. The authors replied to the discussion and the meeting was closed.

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The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

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Register of Lighting Engineers

The following applications for inclusion on the Register of Lighting Engineers have been accepted:—

Mr. R. P. Sayers.
Mr. C. J. Allderidge.
Mr. V. A. Heydon.
Mr. M. E. McCann.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form :—" Trans. Illum. Eng. Soc. (London)."

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